Hf-W EVIDENCE FOR EARLY DIFFERENTIATION OF MARS AND THE EUCRITE PARENT BODY

D-C. Lee and A. N. Halliday, both at Dept. of Geological Sciences, University of Michigan, Ann Arbor, MI 48109 (e-mail: dclee@umich.edu & anh@umich.edu)

Among various short-lived chronometers, ^{182}Hf-^{182}W ($t_{1/2}$ ~ 9 m.y.) is particularly powerful in constraining the timescales of metal / silicate differentiation (such as core formation) in planets and planetesimals [1-3]. Both Hf and W are highly refractory elements and thus are expected to be in roughly chondritic proportions on a planetary object scale in much of the solar system. However, Hf is strongly lithophile and W is moderately siderophile, such that the Hf/W ratio of silicate phases will be much higher than that of coexisting metals. If such segregation occurred during the lifetime of ^{182}Hf, the isotopic abundance of ^{182}W would eventually be greater in the silicate with high Hf/W but be low in the metal with low Hf/W, relative to that found in undifferentiated chondritic material [3]. The magnitude of such an effect in W isotopic composition obtained from various type of samples has been used to place constraints on the age of the Earth's core, the formation of the Moon, and the time scales over which inner solar system objects accreted and differentiated [1-3]. Hf-W isotopic studies of achondrites may shed light on the timing of accretion, differentiation and core formation for other inner solar system parent bodies. A complication is that Hf/W may also be fractionated during silicate melting, as it is in modern terrestrial basaltic magmas, because W is highly incompatible [4]. Here we report the first W isotopic data for SNC meteorites and eucrites in an attempt to better understand these processes as they occurred on Mars and the eucrite parent body.

We have measured the W isotopic compositions and Hf/W ratios of two eucrites, Juvinas and ALHA78132 and five SNC meteorites, Nakhla, Lafayette, Shergotty, ALH84001 and EETA79001. ALH84001 and Shergotty have W isotopic compositions which are close to chondritic and Hf/W ratios (~5) which are close to estimates of the primitive Martian mantle. EETA79001, Lafayette and Nakhla, however, all display excess ^{182}W (ε_W = +2 to +3), relative to the mean of carbonaceous chondrites [3]. The two eucrites Juvinas and ALHA78132 have ε_W of +32 and +22 respectively. These are the first reported measurements of excess ^{182}W and the results can be explained by differentiation of the meteorite protoliths, or just their parent bodies, during the lifetime of ^{182}Hf. For the eucrites, the W isotopic compositions are as expected from their known antiquity [5] and high Hf/W ratios. They yield Hf-W T_{CHUR} model ages in the range 5 to 15 m.y. post-Arispe (assuming ^{182}Hf/^{180}Hf = 2.4 ¥ 10^{-4} at the time of formation of Arispe [3]). The Hf/W ratios of the SNC meteorites display no relationship with W isotopic compositions. Lafayette and Nakhla have low Hf/W ratios (~1-2), presumably reflecting enrichment by small degree partial melts. Assuming a Martian mantle source with a Hf/W in the range 3-4 [6], EETA79001, Lafayette and Nakhla yield Hf-W T_{CHUR} source model ages in the range 5 to 15 m.y. post-Arispe, whereas ALH84001 and Shergotty yield very approximate source model ages closer to 30 m.y. post-Arispe. That this ancient W isotopic heterogeneity has survived provides powerful evidence for extremely early, rapid accretion and differentiation and a lack of subsequent large-scale mixing of the Martian mantle. A similar result was obtained from the ^{146}Sm-^{142}Nd study of the same SNC meteorites [4]. The preliminary Hf-W data presented here display a correspondence with the ^{147}Sm-^{143}Nd data for the same SNC meteorites [7]. Those with radiogenic Nd reflecting time integrated depletion in incompatible elements, EETA79001, Lafayette and Nakhla, also have radiogenic W. Those with less radiogenic Nd, ALH84001 and Shergotty, have W which is closer to chondritic. There are two explanations for this. Firstly, the process of core formation which left the mantle with high Hf/W occurred simultaneously with major silicate melting and depletion of the mantle in lithophile incompatible trace elements, hence high Sm/Nd. This requires a close relationship between the mechanism of core formation and mantle melting. It also requires that major portions of the mantle, as sampled by the source regions of ALH84001 and Shergotty, did not undergo either process to any great extent. The second, perhaps more likely explanation, is that the W isotopic composition of the SNC meteorites simply reflects the effects of early silicate melting with W more incompatible than Hf. In this model, core formation was later (>30 m.y. post-Arispe), and had little impact on the W isotopic composition of the Martian mantle.

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